

The CO content of the Local Group dwarf irregular galaxies IC5152, UGCA438, and the Phoenix dwarf

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ABSTRACT

We present a search for CO(1 → 0) emission in three Local Group dwarf irregular galaxies: IC5152, the Phoenix dwarf, and UGCA438, using the ATNF Mopra radio telescope. Our scans largely cover the optical extent of the galaxies and the stripped HI cloud West of the Phoenix dwarf. Apart from a tentative but non-significant emission peak at one position in the Phoenix dwarf, no significant emission was detected in the CO spectra of these galaxies. For a velocity width of 6 km s^{−1}, we derive 4σ upper limits of 0.03 K km s^{−1}, 0.04 K km s^{−1} and 0.06 K km s^{−1} for IC5152, the Phoenix dwarf and UGCA438, respectively. This is an improvement of over a factor of 10 compared with previous observations of IC5152; the other two galaxies had not yet been observed at millimeter wavelengths. Assuming a Galactic CO-to-H₂ conversion factor, we derive upper limits on the molecular gas mass of 6.2 × 10⁴ M_⊙, 3.7 × 10³ M_⊙ and 1.4 × 10⁵ M_⊙ for IC5152, the Phoenix dwarf and UGCA438, respectively. We investigate two possible causes for the lack of CO emission in these galaxies. On the one hand, there may be a genuine lack of molecular gas in these systems, in spite of the presence of large amounts of neutral gas. However, in the case of IC5152 which is actively forming stars, molecular gas is at least expected to be present in the star forming regions. On the other hand, there may be a large increase in the CO-to-H₂ conversion factor in very low-metallicity dwarfs (−2 ≤ [Fe/H] ≤ −1), making CO a poor tracer of the molecular gas content in dwarf galaxies.

Key words: galaxies : ISM – galaxies : dwarf – galaxies : Local Group – individual galaxies : IC5152, Phoenix dwarf, UGCA438

1 INTRODUCTION

Dwarf galaxies form the most abundant galaxy population in the nearby universe. They represent a wide class of low-mass, low-metallicity stellar systems, with some being gas-rich and presently actively forming stars (dwarf irregulars or dIrrs), while others are gas-poor and apparently formed their stars long ago (dwarf spheroidals or dSph). In between the above extremes exists a subclass of gas-rich dwarfs, called transition-type galaxies, that are not currently forming stars. These objects occupy an evolutionary state in-

termediate between dIrrs and dSphs (Mateo 1998; Grebel 2001).

Most studies of the interstellar medium (ISM) of dwarf galaxies up to now have focused on their atomic gas (HI) content (Young et al. 2003; Conselice et al. 2003; Buyle et al. 2005; Bouchard et al. 2005; Tarchi et al. 2005). Nevertheless if, in accordance with massive galaxies (e.g. the Milky Way), the star formation predominantly takes place in molecular clouds, that are observed to form within cold HI regions (with velocity dispersions of the order of 3 km s^{−1}), one would expect a correlation between the star formation rate and the CO emission rather than between the star formation rate and the amount of cold HI gas. However, so far no such relation has been observed for dIrrs, neither for CO or HI. Generally individual HI clouds are found close to star formation sites, with usually an offset by a few 100 pc. Also, some very dense HI clouds, which surely exceed the density threshold above which star formation is expected to be possible, show no signs of ongoing or recent star formation (Mateo 1998; Begum et al. 2006). These results show that

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the presence of a cold HI component may be a necessary ingredient for star formation, but not a sufficient one: it seems that sometimes a trigger is needed to initiate star formation in dense gas clouds (Taylor et al. 1994; Hernquist & Mihos 1995; Taylor 1997; Pisano & Wilcots 1999). Moreover, the LG (Local Group) dwarf galaxies show a very wide variety of gas masses and star formation rates. Some are quite gas-rich but have little ongoing star formation while others are gas-poor but show evidence for recent star formation (Mateo 1998). In those LG dIrrs that have been detected in CO, the emission usually comes from individual clouds, about 50 pc wide (see Israel 1997; Mateo 1998; De Rijcke et al. 2006, and references therein). The locations of star formation sites, traced by HII regions, correlate very well with regions of CO emission. This shows that the emission of the molecular ISM is a much better tracer of star formation than that of the cold atomic ISM. In order to investigate this interplay between the properties of the atomic and molecular ISM and star formation, we observed a sample of nearby dIrrs: IC5152, the Phoenix dwarf and UGCA438. These galaxies have published HI masses but, with the exception of IC5152, have not yet been surveyed for the presence of a molecular ISM.

CO is often used to trace the molecular gas in galaxies because it is the most abundant (after H_2) and brightest molecule. It is related to the FIR luminosity of the galaxies that is emitted by the warm dust heated by embedded high-mass OB stars, indicating that it indirectly correlates with the current star formation rate (e.g. Gay & Solomon 2004; Murgia et al. 2005). It has also been found that dwarf galaxies below a metallicity of $12 + \log(O/H) \sim 7.9$ are not detected in CO emission (Taylor, Kobulnicky, & Skillman 1998). This suggests that the CO to H_2 conversion factor (X_{CO}) depends on metallicity and that the CO- H_2 relation becomes sharply non-linear around this metallicity (Taylor, Kobulnicky, & Skillman 1998; Taylor & Klein 2001). However, In studying these low-metallicity dIrrs we might be able to shed new light on this cut-off in CO detections.

In the next section we present more details on the three galaxies in our sample. Section 3 describes the new CO observations, and the results are presented and discussed in sections 4 and 5 with a comparison with recent HI observations. Finally we summarise our conclusions in section 6.

2 THE SAMPLE

We selected a sample of 3 dwarf irregular galaxies which fulfilled our selection criteria: being visible during night time, never targeted before for CO observations, are nearby hence in the Local Group and have published or archived (ATCA = Australian Telescope Compact Array) HI observations (St-Germain et al. 1999; Verbiest & Ott 2007).

2.1 IC5152

IC5152 is classified as a dIrr at the outskirts of the LG, at a distance of 2.07 Mpc (Karachentsev et al. 2004), and with a metallicity $[Fe/H] \approx -1$ (Zijlstra & Minniti 1999). Its properties are summarised in Table 1. The optical diameter of IC5152 is about $5'$. The whole central region is a very active

star formation site, and several HII regions have been studied (Webster et al. 1983; Hidalgo-Gómez & Olofsson 2002; Lee, Grebel, & Hodge 2003). IC5152 contains $1.1 \times 10^8 M_\odot$ of HI (Table 2) and is the most gas-rich galaxy in our sample. The HI emission is centered on the optical body of the galaxy, both projected on the sky (Figure 1) as in velocity (Tables 1 and 2).

2.2 Phoenix dwarf

The southern Phoenix dwarf galaxy, situated at a distance of 440 kpc (Karachentsev et al. 2004), is a very interesting system. It has a heliocentric optical radial velocity of $56 \pm 6 \text{ km s}^{-1}$ whereas the HI clouds observed in the Phoenix vicinity have a heliocentric velocity of -23 km s^{-1} (Figure 2 and Table 2), 59 km s^{-1} , 7 km s^{-1} and 140 km s^{-1} . The HI clouds with a velocity of 7 km s^{-1} and 140 km s^{-1} are respectively associated with the Milky Way and the Magellanic Stream. St-Germain et al. (1999) found that the southern HI cloud with velocity component 59 km s^{-1} is, because of its mass and large offset ($\geq 1.2 \text{ kpc}$ south) from the optical body of the galaxy, not associated with Phoenix but with a HVC instead. The characteristics of the HI clouds with velocity -23 km s^{-1} however are consistent with this gas having been associated with Phoenix in the past and being lost by the galaxy after the last event of star formation in the galaxy, about 100 Myr ago (Gallart et al. 2001). Possibly, the HI gas was stripped by the ram pressure of the intergalactic medium (Mayer et al. 2005). If present, molecular clouds, being much more compact than the atomic ISM, will not be stripped and could still be present inside the galaxy's main body. It is a very metal-poor galaxy, with $[Fe/H] = -1.8$ (Held, Saviane, & Momany 1999), with a morphology intermediate between dIrr and dSph. The Phoenix dwarf contains $2.4 \times 10^5 M_\odot$ of HI (see Table 2).

2.3 UGCA438

UGCA438 is a dIrr at a distance of 2.23 Mpc, which places it just outside the LG, making it a likely member of the Sculptor Group (Lee & Byun 1999; Karachentsev et al. 2004). With a metallicity $[Fe/H] = -2$, it is one of the most metal deficient nearby dIrrs. It contains a very young population of stars, but no HII regions. UGCA438 has an HI mass of $5.9 \times 10^6 M_\odot$ (see Table 2). The HI emission, although at the same radial velocity as and covering the whole optical body of UGCA438, is slightly offset to the North of the galaxy (Figure 3).

3 OBSERVATIONS AND DATA REDUCTION

The three galaxies were observed with the new 3mm receiver at the Mopra¹ 22m single-dish radio telescope, at Coonabarabran, Australia. The observations were carried out during the first half of the nights between 2005 October 18 and 30, shortly after the Mopra upgrade. At the time of

¹ The Mopra radio telescope is part of the Australia Telescope which is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO.

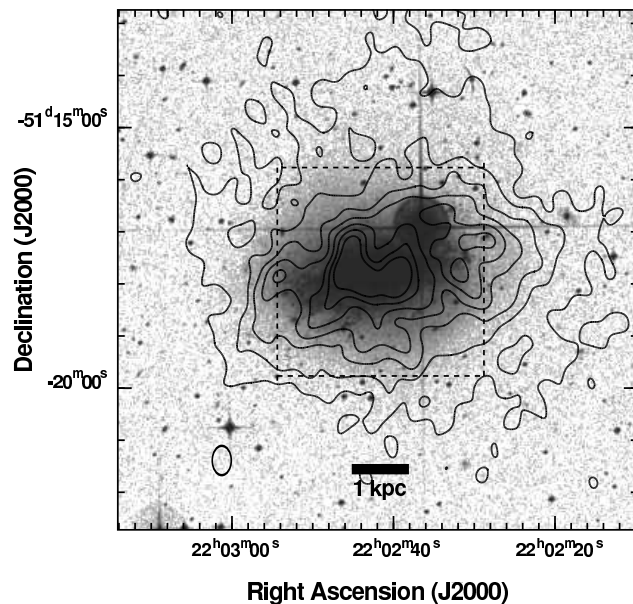
Table 1. Main galaxy properties. The radial velocities are taken from LEDA, the distances from (Karachentsev et al. 2004).

Galaxy	α (J2000) (h:m:s)	δ (J2000) (deg : ' : ")	v_{\odot} (km s $^{-1}$)	D (Mpc)	M_B (mag)	[Fe/H] (dex)	$12 + \log(\text{O}/\text{H})$ (dex)
IC5152	22:02:42.5	-51:17:47	126 ± 5	2.07	-17.2	-1.0	8.00
Phoenix	01:51:06.3	-44:26:41	56 ± 6	0.44	-9.5	-1.8	6.87
UGCA438	23:26:27.6	-32:23:20	62 ± 4	2.23	-12.6	-2.0	7.32

observing the new spectrometer MOPS contained just one setup which produces 4097 channels across a 137.5 MHz band, which we centred on the CO(1 \rightarrow 0) frequency (115.27 GHz), corrected for the Doppler shift for each of the galaxies. The beamsize of the telescope at this frequency is $\sim 33''$ and the velocity resolution of our spectra is 0.08 km s $^{-1}$. The system temperature during the observations varied between 450 and 600 K over the different nights, depending on weather conditions. The pointing of the telescope was recalibrated every 1 to 1.5 hours by observing a nearby SiO maser source (X Pav for IC5152, R Hor for Phoenix and R Aqr for UGCA438).

Due to the proximity of the galaxies, their angular sizes are quite large, hence mosaicing is the only way to cover their optical bodies. We observed a field of $4.75' \times 4.75'$ for IC5152, $1.75' \times 1.75'$ for UGCA438 and $4' \times 4'$ for the Phoenix dwarf covering the entire optical field of each galaxy. An additional field of $4' \times 4'$ which covers the stripped HI cloud was also observed, see Fig. 2. We mapped the fields several times with an 'on-the-fly' mapping procedure on a rectangular Nyquist grid. The mapping is done along equatorial coordinates, with each scan perpendicular to the other to optimise the field coverage. Due to the large size of the field, each scanned row was finalised with observing an empty patch of sky next to the galaxy to accurately perform the sky subtraction. This observing strategy is very different from the CO observations of Taylor, Kobulnicky, & Skillman (1998) and Taylor & Klein (2001), who target just a few positions per galaxy, guided by the presence of cold HI.

The data reduction consists of three parts. First a correction has been performed to align positional and time stamp information. Afterwards the data is fed into Livedata, which performs a baseline subtraction of the spectra. A polynomial of 2nd order was used for the baseline subtraction. Finally, the spectra are spatially combined into a data cube by means of the Gridzilla software.² To convert the CO flux from Kelvin to Jy, we use the Mopra receiver efficiency in the CO band³, which is ~ 30 Jy K $^{-1}$. We investigated the spectra unsmoothed and smoothed to a velocity resolution of 1.28 km s $^{-1}$. In both cases no emission was detected. In order to derive upperlimits (see Table. 2), we Hanning smoothed the spectra to a velocity resolution of ± 6 km s $^{-1}$.

**Figure 1.** IC5152: HI emission intensity contours (the outer contour indicates the $3\sigma \sim 2.7 \times 10^{20} \text{ cm}^{-2}$ level; the other contours each mark a 3σ increase in intensity $\sim 5.2, 7.9, 10.6, \dots \times 10^{20} \text{ cm}^{-2}$) overlaid on an optical DSS image. The extent of the CO map is shown by the dashed rectangle. The ATCA beam of the HI observations is plotted in the bottom left corner. Original HI data from Verbiest & Ott (2007).

3.1 HI observations

All three galaxies, IC 5152, UGCA 438, and the Phoenix dwarf were observed with the Australia Telescope Compact Array (ATCA). For the Phoenix dwarf galaxy we re-reduced archival data (project C569, PI Oosterloo, observed in 1996 September) which are originally published in St-Germain et al. (1999). The beam and the 1σ column density sensitivity of the data, observed in the compact EW 367 array configuration, are $140'' \times 80''$ and $\sim 7 \times 10^{18} \text{ cm}^{-2}$, respectively.

IC 5152 was observed in three array configurations in 2000 January (two 12 h tracks in the 1.5 array configuration; project code C809, PI de Blok), 2004 February (one track in the 750 configuration; C1253, PI Ott), and 2004 April (one track in EW 367; C1253). After standard calibration and imaging, including CLEANing, the final data cube has a beam of $35'' \times 22''$ with a 1σ rms noise of $3.7 \text{ mJy beam}^{-1}$ in a 3.3 km s^{-1} plane, resulting in a 1σ rms column density sensitivity of $\sim 9 \times 10^{19} \text{ cm}^{-2}$.

Similar to IC 5152, UGCA 438 was observed using three

² Both Livedata and Gridzilla are part of the larger AIPS++ package

³ This can be found in the Mopra guide <http://www.narrabri.atnf.csiro.au/mopra/mopragu.pdf>

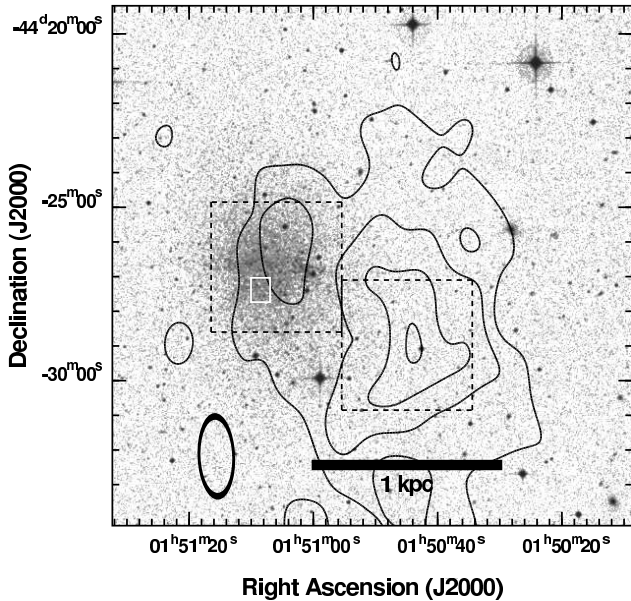


Figure 2. Phoenix: HI emission intensity contours (the outer contour indicates the $3\sigma \sim 2.1 \times 10^{19} \text{ cm}^{-2}$ level; the other contours each mark a 3σ increase in intensity $\sim 4.2, 6.3, 8.4, \dots \times 10^{19} \text{ cm}^{-2}$) overlaid on an optical DSS image. The extent of the CO maps is shown by the dashed rectangles. The white rectangle indicates the position of the possible CO detection (see Figure 4 and text for details). The ATCA beam of the HI observations is plotted in the bottom left corner. Original HI data from Verbiest & Ott (2007).

array configurations, too. All data were collected within project C1253. The three 12h tracks were conducted on 2003 November (1.5 array), 2004 February (750), and 2004 April (EW 367). The resulting reduced data, which will be presented in detail elsewhere, have a 1σ rms sensitivity of $\sim 3 \text{ mJy beam}^{-1}$ in a 1 km s^{-1} plane with a beam of $84'' \times 46''$ in size. The resulting 1σ column density sensitivity is $\sim 5 \times 10^{18} \text{ cm}^{-2}$.

4 RESULTS

In Figures 1 to 3, the dashed rectangles indicate the area of the observed CO maps, covering the optical extent of the galaxies. Although IC5152 and UGCA438 contain a significant amount of neutral gas, we find no CO emission in these galaxies. Also in the HI cloud of the Phoenix dwarf we find no evidence for the presence of CO. Within the Phoenix dwarf itself, some CO might be left. In Figure 4, we show the spectrum of the region indicated by a white rectangular in Figure 2. Exactly at the optical velocity of Phoenix (56 km s^{-1}), there is a small emission peak. If this feature is real, it is unlikely to be related to galactic CO emission since Phoenix lies about 70 degrees above the Galactic plane, which would mean a molecular cloud moving almost perpendicular to the Galactic plane with a velocity of 56 km s^{-1} . However, deeper observations are needed to confirm the detection.

We provide two estimates for the upper limits on the

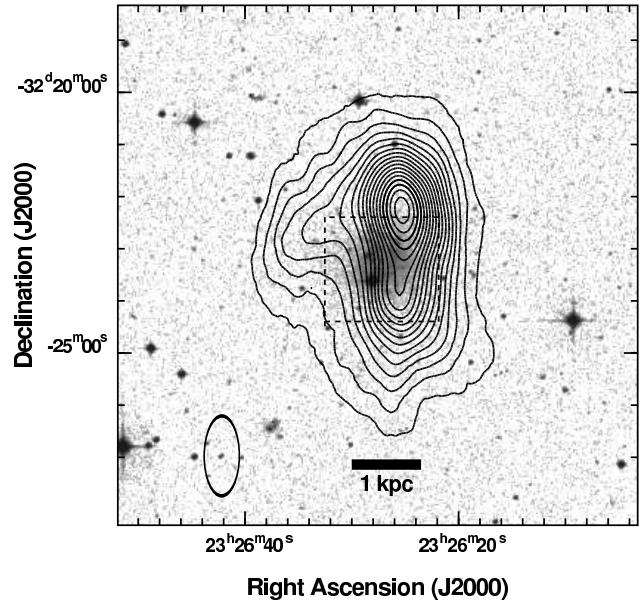


Figure 3. UGCA438: HI emission intensity contours (the outer contour indicates the $3\sigma \sim 1.5 \times 10^{19} \text{ cm}^{-2}$ level; the other contours each mark a 3σ increase in intensity $\sim 3.0, 4.5, 6.0, \dots \times 10^{19} \text{ cm}^{-2}$) overlaid on an optical DSS image. The extent of the CO map is shown by the dashed rectangle. The ATCA beam of the HI observations is plotted in the bottom left corner. Original HI data from Verbiest & Ott (2007).

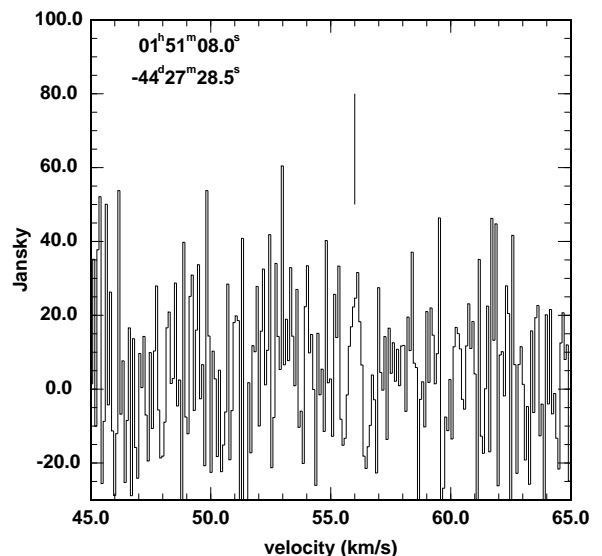


Figure 4. Spectrum of the Phoenix dwarf in the region indicated by a white rectangle in Figure 2. At the optical velocity of Phoenix, $v_{\odot} = 56 \text{ km s}^{-1}$ there is a hint of CO emission, in the form of 8 consecutive non-negative channels.

Table 2. Properties of the cold and molecular ISM. The HI results (of all galaxies) are from Verbiest & Ott (2007) and the CO results are 4σ upper limits, assuming a velocity width of 6 km s^{-1} .

Galaxy	$M(\text{HI})$ (M_\odot)	v_{HI} (km s^{-1})	$W_{50,\text{HI}}$ (km s^{-1})	$S(\text{CO})$ (K km s^{-1})	M_{mol}^a (M_\odot)	M_{mol}^b (M_\odot)
IC5152	1.1×10^8	122 ± 5	86 ± 5	< 0.03	$< 6.2 \times 10^4$	$< 2.4 \times 10^5$
Phoenix	2.4×10^5	-23 ± 3	22 ± 3	< 0.04	$< 3.7 \times 10^3$	$< 8.3 \times 10^4$
UGCA438	5.9×10^6	19 ± 3	19 ± 3	< 0.06	$< 1.4 \times 10^5$	$< 1.6 \times 10^6$

^a using Galactic $X_{\text{CO,Gal}}$ ^b using metallicity dependent $X_{\text{CO,Z}}$ of eqn. (1)

molecular gas masses of the observed galaxies, using on the one hand the Galactic $X_{\text{CO,Gal}} = 3 \times 10^{20} \text{ cm}^{-2} (\text{K km s}^{-1})^{-1}$ (Strong et al. 1988; Scoville & Sanders 1987) and the metallicity dependent conversion factor $X_{\text{CO,Z}}$ given by

$$\log\left(\frac{X_{\text{CO,Z}}}{X_{\text{CO,Gal}}}\right) = (5.95 \pm 0.86) - (0.67 \pm 0.10) \left(12 + \log\left(\frac{\text{O}}{\text{H}}\right)\right) \quad (1)$$

(Roberts et al. 1991; Wilson 1995). The CO flux and molecular gas mass upper limits are listed in Table 2.

5 DISCUSSION

5.1 CO and metal abundance

Taylor, Kobulnicky, & Skillman (1998) found that dwarf galaxies below a metallicity of $12 + \log(\text{O}/\text{H}) \sim 7.9$, or $Z \leq 0.1Z_\odot$ are not detected in CO emission. Based on a study of 121 Northern IRAS-detected dwarf galaxies, Leroy et al. (2005) also find that detections of galaxies with metallicities of $12 + \log(\text{O}/\text{H}) \leq 8.0$ are quite rare.

The metallicity of the ionised gas in the star formation regions in IC5152 has been determined using optical spectroscopy of the HII regions, and ranges from $12 + \log(\text{O}/\text{H}) = 7.92 - 8.35$ (Webster et al. 1983; Hidalgo-Gómez & Olofsson 2002; Lee, Grebel, & Hodge 2003). Phoenix and UGCA438 are not presently forming stars, hence deriving a measurement for their metallicity of the ISM is much more difficult. However in dIrrs, the B -band luminosity is a good predictor of metallicity and we can use the relation (Skillman, Côté, & Miller 2003)

$$12 + \log(\text{O}/\text{H}) = (5.47 \pm 0.48) + (-0.147 \pm 0.029)M_B \quad (2)$$

to estimate the nebular metallicity for these galaxies. In the case of IC5152, this estimate gives $12 + \log(\text{O}/\text{H}) = 8.00$, consistent with the observations. Analogously, we find oxygen abundances $12 + \log(\text{O}/\text{H}) = 6.87$ and 7.32 for Phoenix and UGCA438, respectively. These values, as shown in Table 1, are broadly consistent with the observed $[\text{Fe}/\text{H}]$ abundances, assuming a solar oxygen abundance of $12 + \log(\text{O}/\text{H}) = 8.7$ (Prieto, Lambert, Asplund 2001). In Fig. 5, we add these three dwarf irregular galaxies to those observed by Taylor, Kobulnicky, & Skillman (1998) and Taylor & Klein (2001). We rescaled the CO upper limits measured by us to a $55''$ FWHM beam so as to match the units in the figures presented in Taylor, Kobulnicky, & Skillman (1998) and Taylor & Klein

(2001). The far-infrared luminosity is defined as $L_{\text{FIR}} = 3.65 \times 10^5 D^2 f_{\text{FIR}} L_\odot$. Here, D is the distance, expressed in Mpc, and $f_{\text{FIR}} = 2.58 f_{60} + f_{100}$, with f_{60} and f_{100} the IRAS 60 and 100 micron flux densities, respectively. For galaxies that were not detected by IRAS, we have assumed a limiting 60 and 100 micron flux density of 1 Jy. Since the thermal emission of dust peaks between 50 and 100 micron, L_{FIR} is an indicator of the dust mass.

In a theoretical study of the formation of H_2 at high redshift, Norman & Spaans (1997) showed that cold giant molecular clouds do not form until the metallicity rises to $\sim 0.03 - 0.1 Z_\odot$, or $12 + \log(\text{O}/\text{H}) = 7.0 - 7.6$, at which point there is enough dust to shield molecular clouds from the stellar UV radiation and metals are sufficiently abundant to allow the gas to cool to a few tens of Kelvin. Before that, star formation proceeds in a slow and self-regulated way, as is also observed in nearby dwarf irregular galaxies. As is clear from Fig. 5, no dwarfs with $12 + \log(\text{O}/\text{H}) \lesssim 7.9$ or $\log(L_{\text{FIR}}) \lesssim 7.5$ have been detected in CO so far (Taylor, Kobulnicky, & Skillman 1998; Leroy et al. 2005). This seems to indicate that the non-detections of CO in low-metallicity dIrrs reflect a real lack of dust and hence cold molecular gas in these systems.

An alternative explanation for the non-detections could be a large increase in the CO-to- H_2 conversion factor as the metal abundance in the gas decreases (Leroy et al. 2005).

5.2 Phoenix : the dIrr to dSph transition

The Phoenix dwarf is an interesting object. The HI cloud associated with the Phoenix dwarf is offset with respect to the stellar distribution, probably due to ram pressure stripping by the intergroup medium. Although some traces of molecular gas may still remain within the galaxy's stellar body, cf. our tentative detection of CO($1 \rightarrow 0$) emission at one position, it is unlikely that a new star formation episode can start without a new inflow of neutral gas. This transition-type dIrr/dSph galaxy might therefore evolve into a dSph. No CO emission was found in the HI cloud. This leaves room for two interpretations. The lack of CO might indicate that (i) molecular clouds are not affected by ram pressure stripping in the same way as the neutral gas, as shown by other observations (Crowl et al. 2005), or that (ii) simply no CO is present (like for most low metallicity dwarfs). However, deeper CO observations or observations using other molecular gas tracers are necessary to confirm the evolutionary status of the Phoenix dwarf.

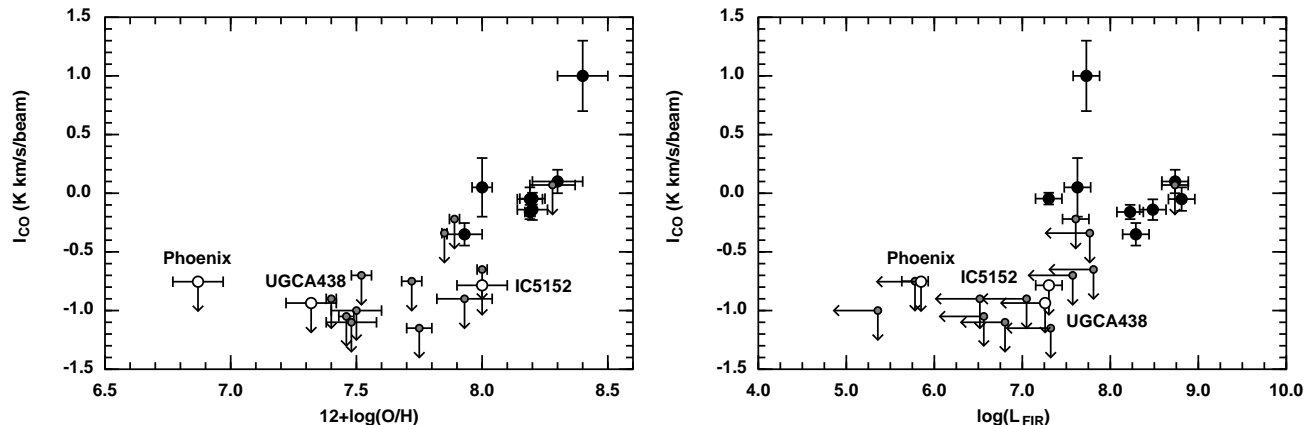


Figure 5. Left panel : the logarithm of the CO(1 \rightarrow 0) intensity, I_{CO} , expressed in K km s $^{-1}$ per 55'' FWHM beam, as in Taylor, Kobulnicky, & Skillman (1998), versus the oxygen abundance, $12 + \log(\text{O}/\text{H})$. Right panel : the CO(1 \rightarrow 0) intensity, I_{CO} versus the logarithm of the far-infrared luminosity, L_{FIR} , calculated from the IRAS 60 and 100 micron flux densities and expressed in solar bolometric luminosities. Black data-points are dwarf galaxies detected by Taylor, Kobulnicky, & Skillman (1998), grey data-points are 4σ upperlimits for the objects not detected by Taylor, Kobulnicky, & Skillman (1998) and Taylor & Klein (2001), white data-points are 4σ upperlimits for the three galaxies presented in this paper. For galaxies that were not detected by IRAS, we have assumed a limiting 60 and 100 micron flux density of 1 Jy. Clearly, no dwarfs with $12 + \log(\text{O}/\text{H}) \lesssim 7.9$ or $L_{\text{FIR}} \lesssim 7.5$ have been detected in CO(1 \rightarrow 0) emission so far.

6 CONCLUSIONS

We have obtained very deep CO emission maps of three Local Group dwarf irregular galaxies: IC5152, the Phoenix dwarf, and UGCA438. We did not detect CO emission in these galaxies, with 4σ upper limits of $0.03 - 0.06$ K km s $^{-1}$ over a 6 km/s velocity width. Our results are summarized in Table 2. As is obvious from the HI maps of these galaxies, our maps cover both their stellar and HI distributions.

There could be two possible explanations for the lack of CO emission in these galaxies. On the one hand, there could be a genuine lack of molecular gas in these systems, in spite of the presence of large amounts of neutral gas. On the other hand, the CO-to-H $_2$ conversion factor might become very large in these very low-metallicity dwarfs, making CO a poor tracer of the molecular gas content. If this is indeed the case, this has implications for galaxy formation scenarios in the early universe, since molecules are an important coolant of the ISM. In the absence of CO, star formation might not proceed as we observe it today in our Galaxy. We find no correlation between the composition of the interstellar medium and the star-formation rate. All galaxies have HI associated with them and Phoenix is the only one with a tentative CO detection. However, only IC5152 is actively forming stars. In the case of the Phoenix dwarf, we are most likely witnessing the process of the transition of a dIrr to a dSph galaxy, where the neutral gas has been stripped from the galaxy. There might be a hint that some molecular gas is still present in the galaxy, but this needs further confirmation.

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